The Theia Detector Excavation – Input from the LBNE Water Cerenkov Detector Design Report

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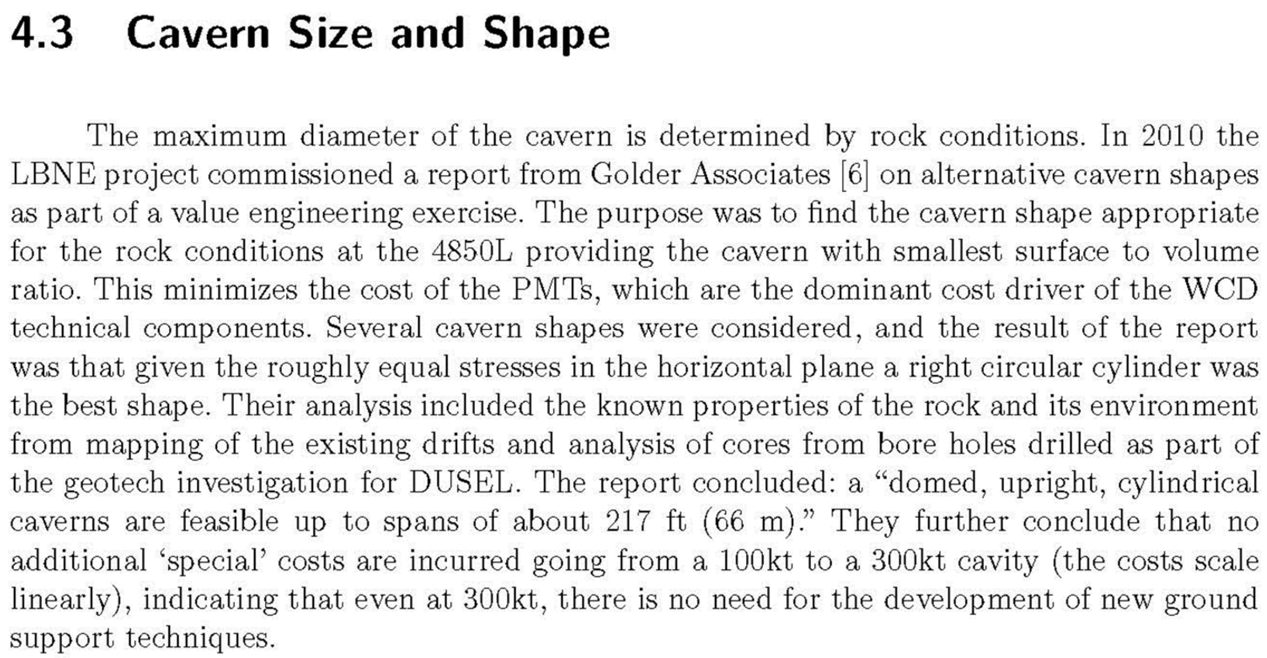
Between 2006 – 2011, we designed water Cerenkov Detectors with volumes from 100 ktonnes to 300 ktonnes for the LBNE at SURF2222.

- **Statement from the Conceptual Design Report, vol.4, of the LBNE WCD**.



4.3 Cavern Size and Shape

The maximum diameter of the cavern is determined by rock conditions. In 2010 the LBNE project commissioned a report from Golder Associates [6] on alternative cavern shapes as part of a value engineering exercise. The purpose was to find the cavern shape appropriate for the rock conditions at the 4850L providing the cavern with smallest surface to volume ratio. This minimizes the cost of the PMTs, which are the dominant cost driver of the WCD technical components. Several cavern shapes were considered, and the result of the report was that given the roughly equal stresses in the horizontal plane a right circular cylinder was the best shape. Their analysis included the known properties of the rock and its environment from mapping of the existing drifts and analysis of cores from bore holes drilled as part of the geotech investigation for DUSEL. The report concluded: a "domed, upright, cylindrical caverns are feasible up to spans of about 217 ft (66 m)." They further conclude that no additional 'special' costs are incurred going from a 100kt to a 300kt cavity (the costs scale linearly), indicating that even at 300kt, there is no need for the development of new ground support techniques.

Cost Savings

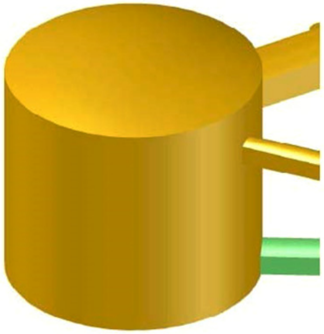
- The LBNE water Cerenkov Detector CDR (conceptual design report) provided a thoroughly studied and evaluated detector design that included chamber excavation, chamber liner and rock water seepage control, PMT installation, cabling, water cooling and purification, etc. The PMT installation plan permits adding PMTs to the full detector – consistent with Ed Blucher's suggestion of a phased detector instrumentation and sensitivity.

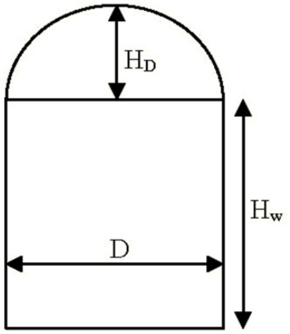
- Some of the construction and underground facility repair costs in this WCD report do not apply to Theia since they are already done or budgeted elsewhere. Also there may be other savings for Theia compared to the Water CD budget estimate.

- One significant example are cost savings achieved by linking the Theia excavation to that of DUNE. That is, by beginning the Theia excavation before the DUNE excavation ends, we avoid an additional round of mobilization/demobilization, the costs of bringing equipment and personnel into the undergnd lab and then removing them at the end.

- There may also be savings in sharing a common electrical substation and other similar facilities.

Setting Excavation Parameters

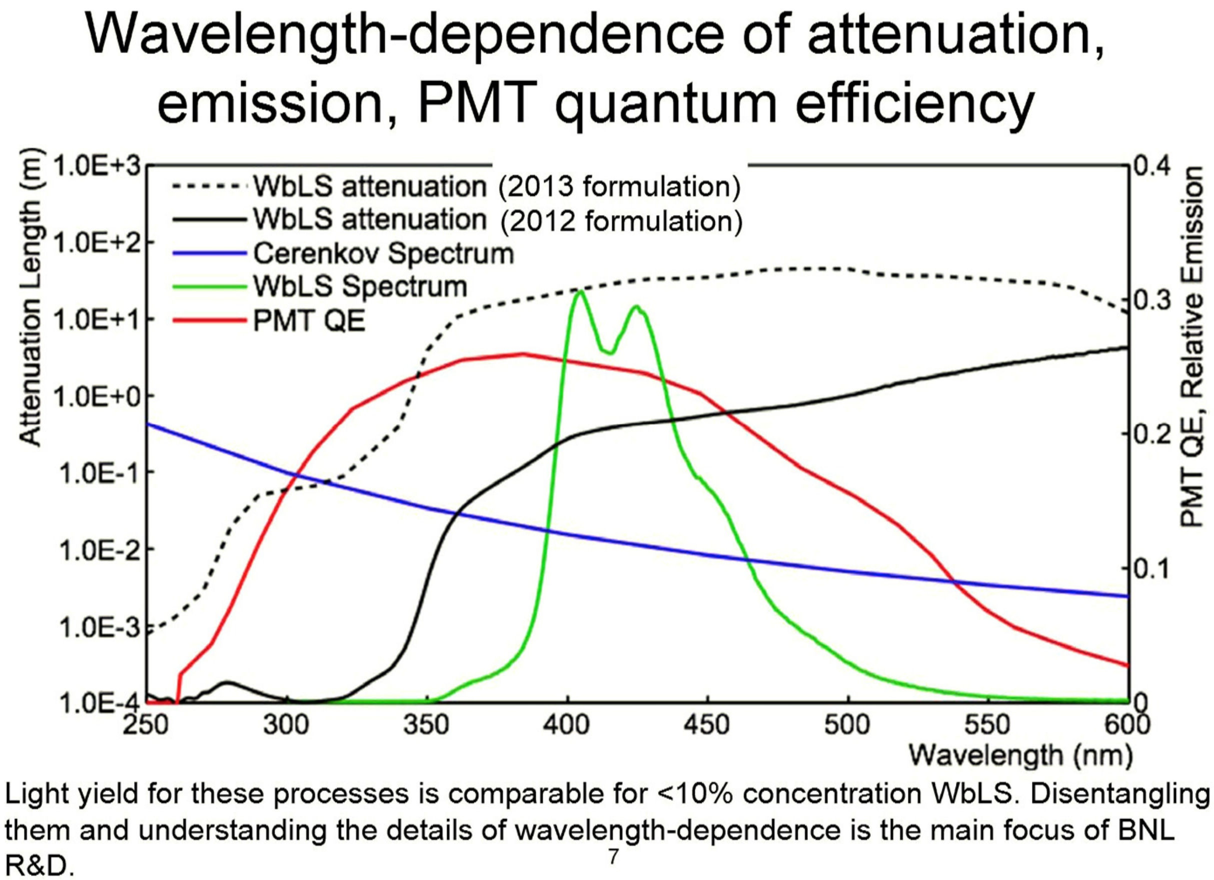




The maximum diameter, D, is determined by the lesser of (a) the geological constraint, 66 m, and (b) The light absorption length of the medium, discussed on the next slide.

The maximum detector fill height, H_w, is determined by the pressure tolerance of the PMTs. Milind Diwan and associates have determined that to be 20 atm or 200 m. Other considerations limit this depth to ~ 70 m.

The dome height, H_D, is determined by geological considerations and is typically D/4.



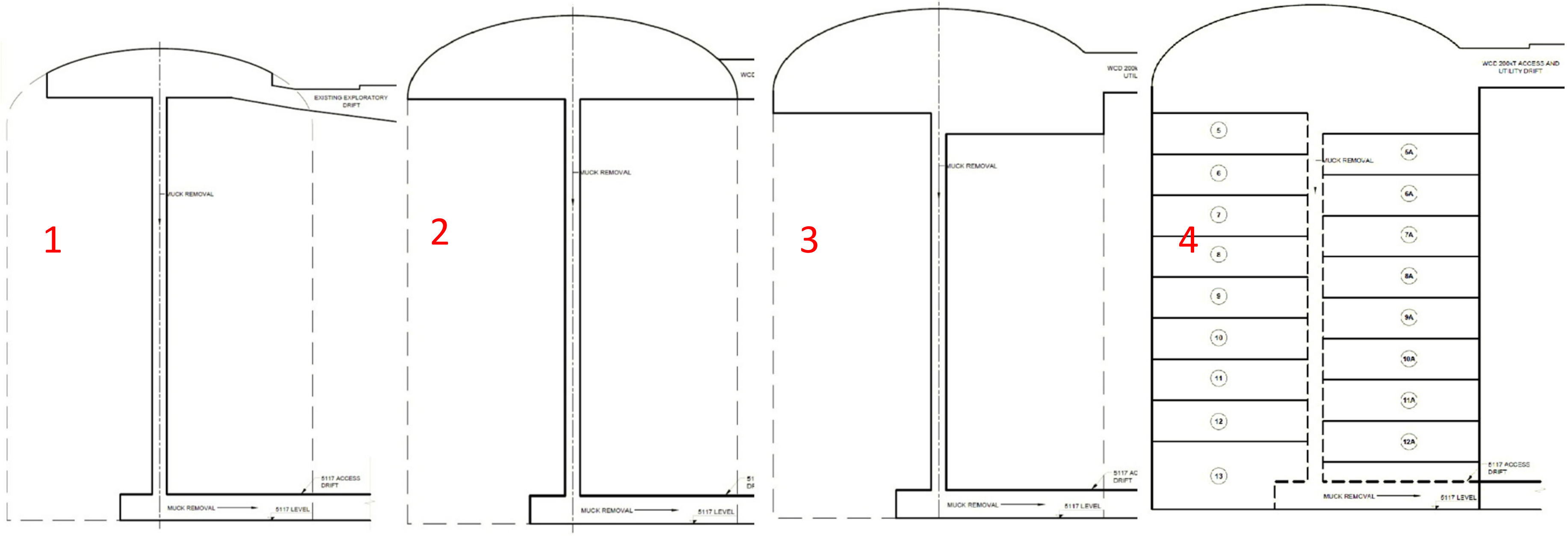
Wavelength-dependence of attenuation, emission, PMT quantum efficiency

Light yield for these processes is comparable for <10% concentration WbLS. Disentangling them and understanding the details of wavelength-dependence is the main focus of BNL R&D.

<u>This plot & data provided by Minfang Yeh & Milind Diwan</u>.

The WbLS attenuation length in the WbLS emssion region, 400 – 450 nm, is about 20 m. Part of this is due to absorption and the rest to scattering. In a Cerenkov detector the scattered light is lost to the signal and contributes to the background. Since scintillation light is emitted isotropically, the scattered light still contributes to the signal, albeit it with a brief time delay. Minfang's estimate is that the absorption length is ≥ 50 m.

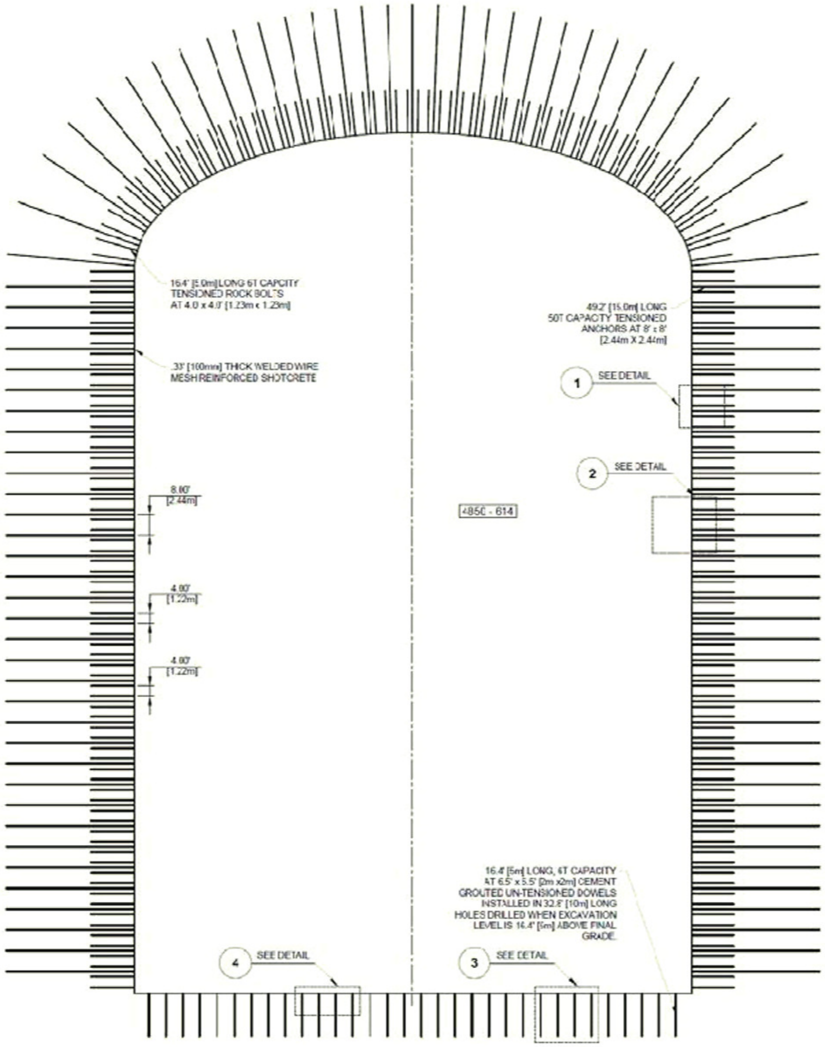
Excavation Sequence (David Vardiman)

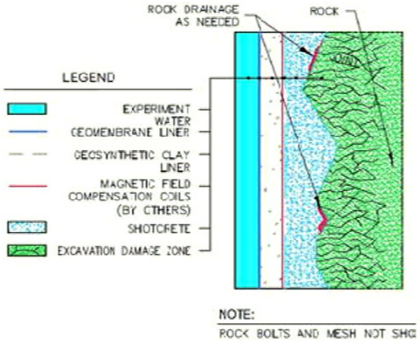


The excavation begins (left) with tunnels at the top and bottom of the planned chamber. Next, a vertical hole is drilled from top to bottom and a reaming tool is used to enlarge the hole to about 3 m diameter. This is the chute through which the excavated rock is dropped to the bottom. Now there begins a sequence of (a) drilling holes for explosives, (b) blasting, (c) “mucking” – removing the loose rock, and (d) supporting the newly exposed rock walls with a variety of rock bolts, including long cable bolts. Figure 4 (right) shows a typical excavation series pattern, blasting 3 – 5 m high thicknesses of rock.

A recent development is to put the explosives into concentric rings and phase shift the blast time of these rings so that there is phase cancellation at the wall of the chamber. This prevents blast damage to the chamber walls.

Final Excavation with Bolts & Liner Section



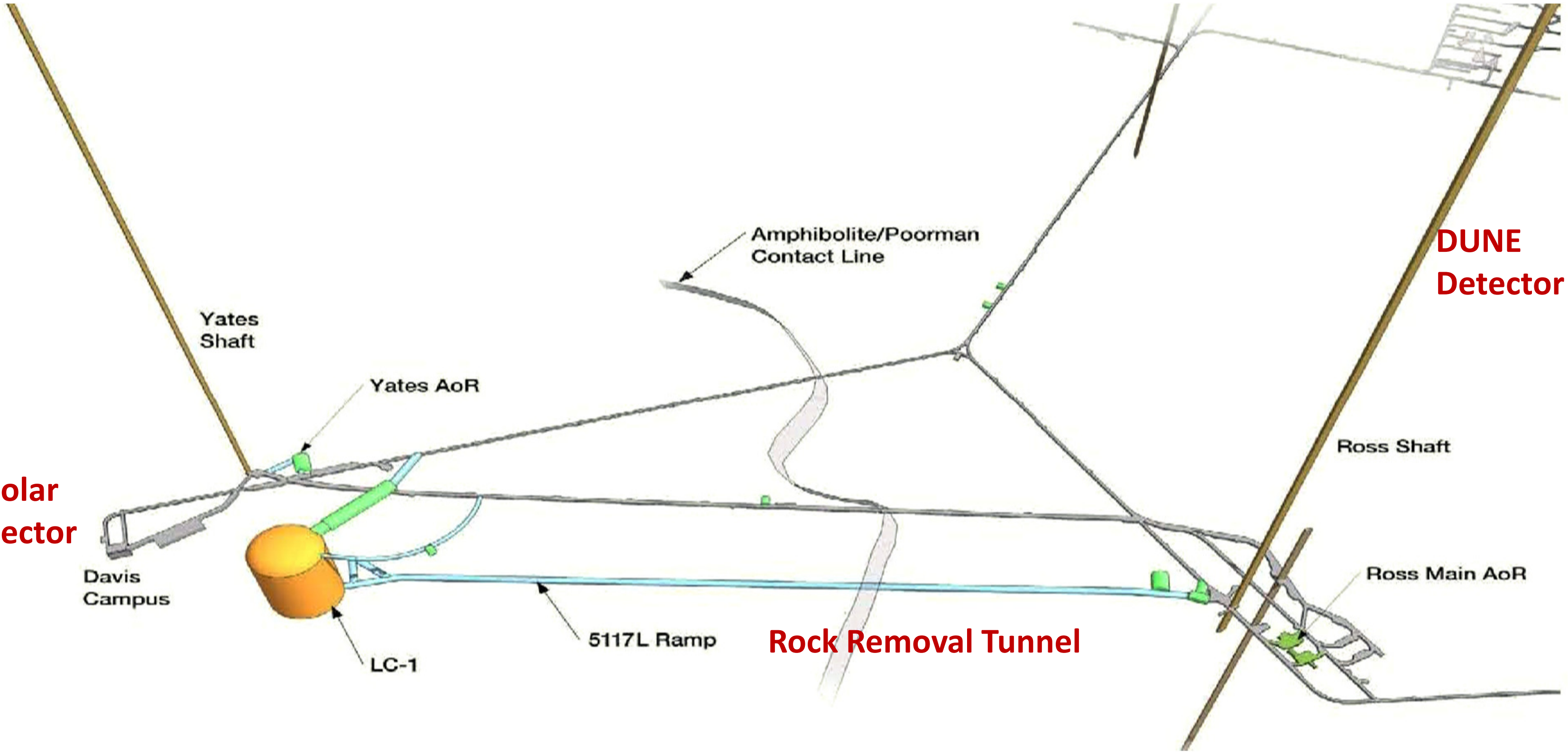


1 **VESSEL LINER DETAIL**
N.T.S.

Cable bolts shown are ~16 m long and rock bolts ~5 m long.

The liner is designed to wick away water seepage from the rock, provide a smoothing filler to protect the inner sanitary liner from protruding rocks and provide space for magnetic field compensation coils.

Layout of the 4850 Level at SURF



Cl Solar Detector

DUNE Detector

Rock Removal Tunnel

Detector Dimensions – 100 kt & 200 kt

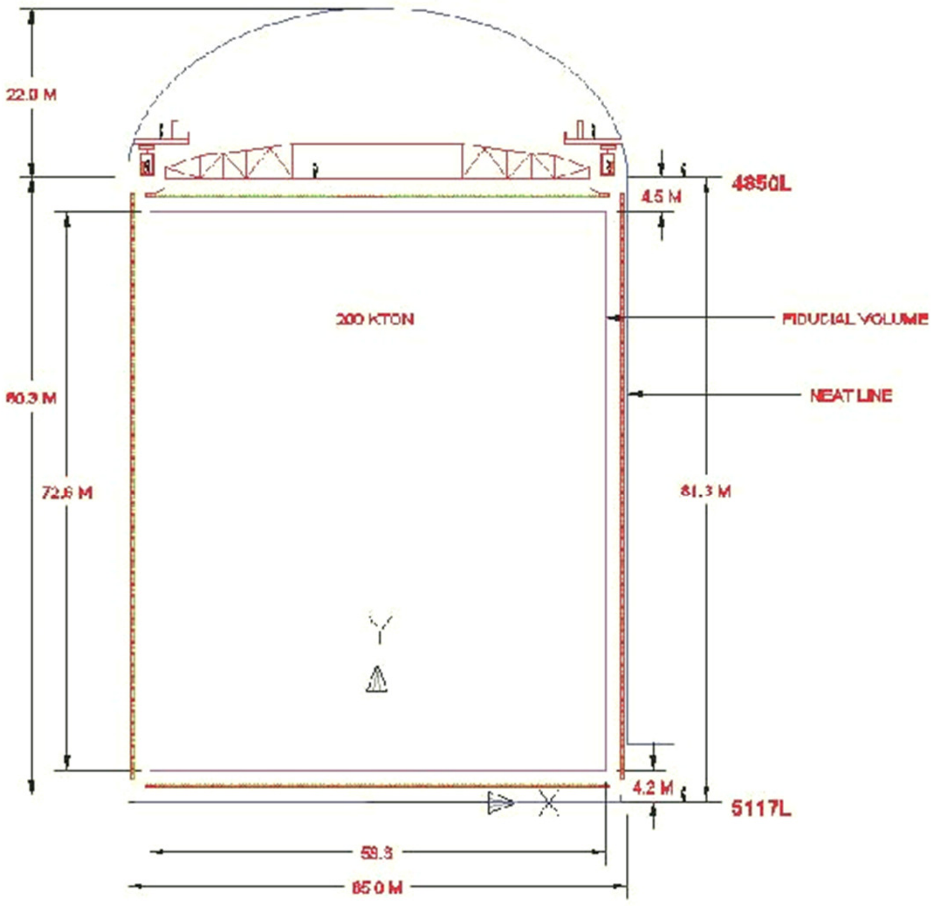


Figure 4–1: Cross-sectional view of 200 kt cavity, with dimensions labelled.

Fiducial Mass	200 kt	100 kt
Excavated diameter	65 m	53 m
Fiducial diameter	59 m	47 m
Rock cylinder ht.	80 m	64 m
Fiducial cylinder ht.	73 m	58 m
Dome	22 m	15 m

The dimensions of the 100 kt fiducial mass detector are compatible with the light absorption length discussed earlier.

200 kt Underground Facilities & Comments for WbLS Plan

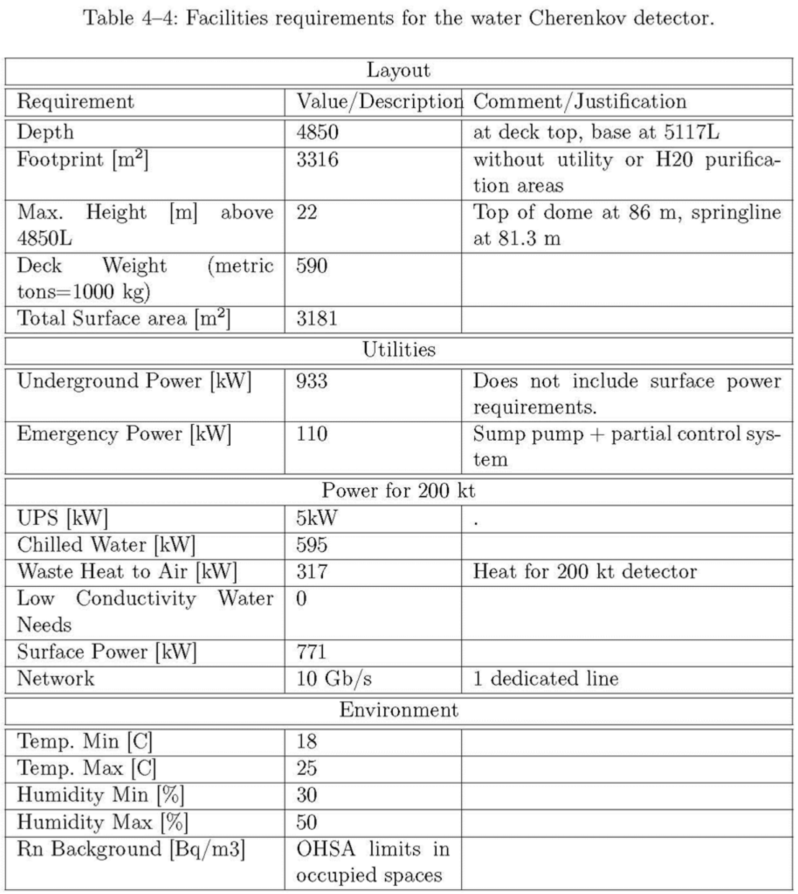


Table 4–4: Facilities requirements for the water Cherenkov detector.

Layout		
Requirement	Value/Description	Comment/Justification
Depth	4850	at deck top, base at 5117L
Footprint [m^2]	3316	without utility or H20 purification areas
Max. Height [m] above 4850L	22	Top of dome at 86 m, springline at 81.3 m
Deck Weight (metric tons=1000 kg)	590	
Total Surface area [m^2]	3181	
Utilities		
Underground Power [kW]	933	Does not include surface power requirements.
Emergency Power [kW]	110	Sump pump + partial control system
Power for 200 kt		
UPS [kW]	5kW	.
Chilled Water [kW]	595	
Waste Heat to Air [kW]	317	Heat for 200 kt detector
Low Conductivity Water Needs	0	
Surface Power [kW]	771	
Network	10 Gb/s	1 dedicated line
Environment		
Temp. Min [C]	18	
Temp. Max [C]	25	
Humidity Min [%]	30	
Humidity Max [%]	50	
Rn Background [Bq/m3]	OHSA limits in occupied spaces	

- **Temperatures – The rock is ~32^{o}C and the circulating air is ~20^{o}C. The WCD plan was to set the detector fill at 13^{o}C. This created a very large cooling power demand – see table. The dominant heat flow into the detector was from the top rather from the rock sides. If the WbLS is to be operated appreciably below 20^{o}C, then it might be prudent to install a thick insulating top cover.**

- **Also, the total detector power requirements should be carefully evaluated. Excessive power capacity can be a steep driver of conventional facilities cost.**

- **Similar comments apply to maximum people occupancy.**

Summary

1) The Sanford (Homestake) rock has been extensively investigated and found capable of stable excavations of over 65 m diameter. These studies include a significant number of test bores and rock core studies as well as investigations by the Large Cavern Advisory Board. Finally, the proposed rock location is very close to and in the same rock formation as the Chlorine Solar Neutrino Detector, which was excavated in 1965 and remained in its original state with no rock failure until 2010 when it was converted into the LUX experiment.

2) Detailed rock excavation studies for a 100 – 300 kt chamber have been carried out by Golder Associates, a respected mine construction firm.

3) The chamber site is deep, ~1450 m of rock, and so well shielded from cosmic rays. It is also in the forthcoming intense long range neutrino beam from Fermilab. That permits neutrino beam studies during beam pulse on time and non-beam physics between pulses.

4) The Sanford Lab is a purely scientific endeavor involving multiple experimental groups in a comfortable and pleasant research setting.